participants discussed the assessment criteria with the students before initiating the assessment activity and often provided exemplars.

> I tell them that I will be marking it and I tell them that they will be evaluating it as well. I talk to them about, or I usually write down on the overhead with them, 'What would really make a good assignment,' and some of the things that would tend to make a satisfactory kind of assignment and what would be something that would be considered to be not such a great assignment and we will write down together as a group some things to look for. (Julia, focus-group interview)

Some of the participants increased students' understanding of how authentic assessment applied to them by having the students help in creating rubrics for specific activities.

### *Resources*

Several of the participants mentioned a lack of resources or the time for finding and adapting resources as a major stumbling block to their use of authentic assessment. Even when resources were located, they were not always suitable to a teacher's needs. Teachers need exemplars of problems, assessment tools, and samples of student work to assist them in determining levels of achievement. Miriam described the lack of time for finding and developing resources. Julia often found it difficult to create new activities to suit each unit and recognized that she often needed a resource to stimulate an idea that she could develop. Professional development and courses in authentic assessment are ways to help teachers locate, adapt, or develop resources. Dave suggested,

> What would be good would be a course of some kind in this stuff. It truly would be. It would take people who were excited and kind of lessen their load a bit. I mean it is hard to keep recreating everything by yourself. And for people who haven't tried it, it could be a relatively non-threatening introduction. I mean, if they could get some ready-made rubrics and activities that go with them then there might be a way to get them started. (Dave, interview transcript)

As a new department head, Dave recognized that teachers have very little time to investigate and implement new assessment strategies in their classrooms. Gwen also referred to the creation of activities' requiring a great deal of time and Luke reiterated the need for teachers to find time to share the resources and ideas that they have.

### *Attitude towards professional growth*

Throughout this study, the participants' high level of commitment to professional growth was apparent. For instance, all of the participants had gone beyond the mandatory educational training to partake in or complete specialist courses, as in Dave's, Julia's, and Miriam's cases, or Master's degrees, as in Gwen's, Luke's, Dave's, and Miriam's cases. The participants were engaged not only in lifelong learning but also in seeking new resources, adapting their teaching, and generally enhancing their professional expertise. It has been suggested, 'Mathematics teachers need to continually explore mathematical concepts and ideas to be better prepared for different learning situations' (McDougall, 1997, p. 163). These findings are supported by the practice of the participants.

Examples of the teachers' commitment to professional growth occurred constantly. All of the participants attended workshops and conferences on their own time. Several of the participants stated that they started each new school year with a pledge to themselves to try one or two specific new ideas, such as introducing rubrics or portfolios.

> For instance, this year I am going to generate three more activities with rubrics, let's say. I do that. I commit myself to do that because I sometimes figure that if I don't do that then nothing happens. Because it is much easier to slide back into the traditional, or whatever you did last year (whether it was traditional or not). It is much easier to slide back. (Dave, interview transcript)

There was also significant evidence of these teachers as reflective practitioners:

> A lot of what I think about is what can I do differently? What didn't go well? What can I improve on? I often think okay, next year when I do this I'm going to do this, this way. Even sometimes I'll make notes to myself after I've done an activity that this needs to be worked on or I'll think of something like 'Gee a great way to start this section off would have been ...' (Julia, interview transcript)

The participants were willing to try new ideas and take risks. Gwen spoke of her willingness to try new things when she spoke of why she decided to use portfolios: 'Again, it is just more experimental. I wanted to try something different and see how it works, if it works and to see the amount of work it requires from students and from me and to see if it is worth it and if it is manageable' (Gwen, post-observation interview). This willingness to take risks requires that the teacher be confident of her/his own mathematical knowledge and insight. It would appear as though the participants solved the problems of creating a meaningful mathematics curriculum and displayed the characteristics they encouraged in their students: risk taking, confidence, collaborative work, and the use of appropriate resources. These characteristics were previously identified in several studies (Brown & Baird, 1993; Carpenter & Fennema, 1991) as being strong influences on teachers' use of problem-solving and authentic-assessment activities. Luke noted, 'You really have to believe [that this is the right thing to do]' (Luke, first interview).

### *Administrative support*

School and board administrations can support new assessment practices in a variety of ways. They can help to provide time for teachers to collaborate, support professional development, communicate with parents and students about new assessment methods, and help to develop reporting methods that are aligned with assessment practices. Administrative support to facilitate finding time for teachers to work together was a strong influence on several of the participants. For instance, Miriam felt supported by a principal who found creative ways to build time into the schedule of the day for teachers to work together. Support for teachers' work is essential. 'Even if teachers are convinced of the benefits of using more innovative methods to evaluate their students, they are unlikely to succeed unless their supervisors, students, parents—and even their fellow teachers—understand and support their break with tradition' (Webb & Coxford, 1993, p. 13). Teachers need time to develop and find resources that are samples of good instructional and assessment practices and to organize and analyse samples of student work.

Reporting methods that align with new assessment practices are also useful. In Gwen and Julia's case, support through a compatible reporting system for Grade 9 encouraged a variety of assessment methods and provided parents with detailed information about student achievement. Administrative support is also required to educate parents and students as to new methods of assessment and reporting, thus increasing validity and accountability. Parents and students are very oriented towards percentage grades, especially in the senior levels. Parents, teachers, and students need more information about the value of authentic assessment techniques if these techniques are going to be credible. The creation and explanation of sample activities, sample assessments, and exemplars of different levels of work would be helpful to parents and students, as well as to teachers.

## Conclusions

This study provides significant information about teachers' experiences in developing authentic assessment activities for their classrooms. How and why teachers use authentic assessment, the problems they encounter, and the ways that they can be supported are summarized in this concluding section.

The teachers in this study chose to use authentic assessment techniques because they were using innovative approaches to teaching mathematics. They believed that learning mathematics was more than practising algorithms and wanted to give students the opportunity to explore mathematical concepts, apply mathematics in a variety of situations, and become confident problem solvers. Their view of mathematics teaching and learning incorporated problem-solving challenges, communication of the process of mathematics, group work, and self-reflection on the process of learning mathematics, as well as developing traditional skills. They found that as they incorporated new instructional strategies in their practice, the sole use of paper-and-pencil tests was not comprehensive enough to show what students knew and could do. Thus, they developed and implemented other assessment instruments, such as portfolios, performance tasks, journals, and group projects.

The teachers faced several challenges. Their view of mathematics teaching and learning was often different from the views of their colleagues. In most cases, they were working on their own and felt a sense of isolation. They also were trying to implement innovative ideas that did not necessarily fit into a traditional mathematics curriculum and assessments that were more than a traditional examination. Often, they felt that they were met with skepticism from their colleagues. They also struggled with matching these assessment instruments with traditional reporting methods, for they felt as though the assessment evidence that they gathered could provide a great deal of information that could not fully be shown with a single numeric mark.

Participants suggested several ways that they could be supported. They felt that a problems-based curriculum would support their instructional and assessment strategies. They also recognized the importance of developing a collaborative teacher culture, particularly as teachers were struggling with new methods. They also valued the important role that administrators played in facilitating change in assessment practices.

The teachers in this study were constantly torn between delivering a curriculum that listed content topics and assumed a traditional teaching style and offering a problems-rich curriculum with a variety of teaching styles. If engaging instructional tasks and authentic assessment activities are to be implemented, then a curriculum that encourages and promotes such activities should be in place.

However, implementing a problems-rich curriculum may require much more than a new curriculum. This study examined the practice of teachers who chose to use authentic assessment in their classrooms. Their choices grew out of their view of mathematics, which in turn affected their instructional practice. They had a desire to increase student understanding through problem solving and incorporated this in their classroom instruction. They recognized a need to implement new assessment techniques and thus chose to grapple with issues of implementing these techniques. Thus, some would wonder whether educators are able to learn anything that would be applicable to teachers who are mandated to implement authentic assessment techniques. What can be said of teachers who may be expected to employ authentic assessment in their classrooms and do not 'believe,' as Luke suggests is necessary? The implementation of new assessment strategies must be coupled with or preceded by the implementation of instructional strategies that focus on problem solving and exploration. As well, teachers need to have an understanding of why they are implementing such strategies, so that classroom practices are purposeful. Teachers match their instructional and assessment style with how they think about mathematics and how they perceive students learn mathematics. Shepard (2000) suggests that implementing a reformed vision of curriculum and assessment can be overwhelming: 'Being able to ask the right questions at the right time, anticipate conceptual pitfalls, and have at the ready a repertoire of tasks that will help students take the next steps requires deep knowledge of subject matter. Teachers also need help in learning to use assessment in new ways' (Shepard, 2000, p. 12). New ideas about assessment and instruction are apt to be at odds with prevailing beliefs. This was shown by the sense of isolation of the participants. Teachers will need time to reflect on their own beliefs about mathematics and mathematics teaching and learning. They will also need to be exposed to new knowledge about how students learn and assimilate this knowledge before they will be able to think about changes in practice. New methods may need to be introduced gradually. Teachers who are new to the use of authentic assessment may be most comfortable with a course of study that gradually introduces relevant problem-solving activities and accompanying assessment methods.

A collaborative teacher culture needs to be supported and encouraged to serve as informal professional development that allows teachers to develop expertise and share resources. Sustained professional development and collective participation encourages professional communication and supports change in teaching practice (Garet, Porter, Desimone, Birman, & Yoon, 2001). Such collaboration also helps to develop the consistency in assessment practices that leads to greater accountability. Teachers also develop a system of support to counteract the feeling of isolation reported in several inquiries. Roulet (1998) examined the practice of exemplary mathematics teachers and his description of his participants, Randy and Jonathan, concurs with the experiences of isolation of the teachers in this study. The need for a collaborative work culture seems especially valid for teachers implementing new ideas that make them uneasy. Issues of increasing expertise, maintaining consistency, sharing resources, and providing mutual support will be best addressed through a coordinated effort.

Administrative support is required to give teachers time to learn new techniques and to share their knowledge, resources, frustrations, and successes. Administrators can also help to develop an understanding of the purpose of using authentic assessment. Increasing the validity and understanding of authentic assessment so that students and parents are more comfortable with incorporating authentic assessment in evaluation is critical.

The teachers in the five case studies chose to use authentic assessment and had been incorporating changes in curriculum and assessment practices as part of their own professional growth. Although they were not required to adopt authentic assessment practices, their stories have value to those who are expected to incorporate new assessment techniques into their practice. As well, the study's relevance is not restricted to mathematics educators but also speaks to other disciplines. Understanding teachers' experiences with authentic assessment helps the educational community recognize how to support teachers in assessment. Further, this article outlines the needs of these teachers and the conditions that support professional growth in the area of authentic assessment in mathematics.

## References

Borko, H. (1997). Teachers' developing ideas and practices about mathematics performance assessment: Success, stumbling blocks, and implications for professional development. *Teaching and Teacher Education, 13*(3), 259–278.

Brown, C.A., & Baird, J. (1993). Inside the teacher: Knowledge, beliefs and attitudes. In P. Wilson (Ed.), *Research Ideas for the Classroom: High School Mathematics* (pp. 245–259). New York: MacMillan.

Carpenter, T.P., & Fennema, E. (1991). Research and cognitively guided instruction. In E. Fennema, T.P. Carpenter, & S.J. Lamon (Eds.), *Integrating research on teaching and learning mathematics* (pp. 1–16). Albany, NY: State University of New York.

Clarke, David J. (1992). Activating assessment alternatives in mathematics. *Arithmetic Teacher, 39*(6), 24–29.

Davis, R.B., Maher, C.A., & Noddings, N. (1990). Introduction: Constructivist views on the teaching and learning of mathematics. In Constructivist views on the teaching and learning of mathematics [monograph 4]. *Journal for Research in Mathematics Education,* 1–3.

Even, R., and Tirosh, D. (2002). Teacher knowledge and understanding of students' mathematical learning. In L.D. English (Ed.), *Handbook of international research in mathematics education* (pp. 219–240). Mahway, NJ: Lawrence Erlbaum.

Flexer, R.J. (1995). *How 'messing about' with performance assessment in mathematics affects what happens in classrooms.* Los Angeles, CA: National Center for Research on Evaluation, Standards, and Student Testing.

Franke, M.L., & Carey, D.A. (1997). Young children's perceptions of mathematics in problem-solving environments. *Journal for Research in Mathematics Education, 28*(1), 8–25.

Garet, M., Porter, A., Desimone, L., Birman, B., & Yoon, K.S. (2001). What makes professional development effective? Results from a national sample of teachers. *American Educational Research Journal, 38*(4), 915–945.

Ginsberg, H.P., Lopez, L.S., Mukhopadhyay, S., Yamamoto, T., Willis, M., & Kelly, M.S. (1992). Assessing understandings of arithmetic. In R. Lesh & S. Lamon (Eds.), *Assessment of authentic performance in school mathematics* (pp. 265–292). Washington, DC: American Association for the Advancement of Science.

Goldin, G. (1992). Towards an assessment framework for school mathematics. In R. Lesh & S. Lamon (Eds.), *Assessment of authentic performance in school mathematics* (pp. 63–88). Washington, DC: American Association for the Advancement of Science.

Hart, D. (1994). *Authentic assessment.* Menlo Park, CA: Addison-Wesley.

Kulm, G. (1994). *Mathematics assessment: What works in the classroom.* San Francisco, CA: Jossey-Bass.

Lampert, M. (2001). *Teaching problems and the problems of teaching.* New Haven, CT: Yale University Press.

Lehman, M.F. (1995). *Assessing mathematics performance assessment: A continuing process.* East Lansing, MI: National Center for Research on Teacher Learning.

Lester, F.K., & Kroll, D.L. (1990). Assessing student growth in mathematical problem solving. In G. Kulm (Ed.), *Assessing higher order thinking in mathematics* (pp. 52–70). Washington, DC: American Association for the Advancement of Science.

McDougall, D.E. (1997). *Mathematics teachers' needs in dynamic geometric computer environments: In search of control.* Unpublished doctoral dissertation, Ontario Institute for Studies in Education of the University of Toronto.

Maher, C.A., Davis, R.B., & Alston, A. (1992). A teacher's struggle to assess student cognitive growth. In R. Lesh & S. Lamon (Eds.), *Assessment of authentic performance in school mathe-*

*matics* (pp. 249–264). Washington, DC: American Association for the Advancement of Science.

Mathematical Sciences Education Board and National Research Council. (1993). *Measuring up: Prototypes for mathematics assessment.* Washington, DC: National Academy Press.

Morgan, C., & Watson, A. (2002). The interpretative nature of assessment. *Journal for Research in Mathematics Education, 33*(2), 78–110.

Morony, W., & Olssen, K. (1994). Support for informal assessment in mathematics in the context of standards referenced. *Educational Studies in Mathematics, 27,* 387–399.

National Commission on Excellence in Education. (1983). *A nation at risk: The imperative for educational reform.* Washington, DC: US Government Printing Office.

National Council of Teachers of Mathematics. (1989). *Curriculum and evaluation standards for school mathematics.* Reston, VA: Author.

National Council of Teachers of Mathematics. (2000). *Principles and standards for school mathematics.* Reston, VA: Author.

Neill, D.M., & Medina, N.J. (1989). Standardized testing: Harmful to educational health. *Phi Delta Kappan, 70,* 688–697.

Romberg, T.A., Zarinnia, E.A. & Collis, K.F. (1990). *A new world view of assessment in mathematics.* In G. Kulm (Ed.), *Assessing higher order thinking in mathematics* (pp. 21–38). Washington, DC: American Association for the Advancement of Science.

Roulet, R.G. (1998). *Exemplary mathematics teachers: Subject conceptions and instructional practices.* Unpublished doctoral dissertation, Ontario Institute for Studies in Education of the University of Toronto.

Rowley, G., Leder, G., and Brew, C. (1994, November). *Learning from assessment: Mathematics and the VCE.* Paper presented at the annual conference of the Australian Association for Research in Education, Newcastle.

Rowley, G., Brew, C., and Ryan, J.T. (1996, April). *Statewide assessment in mathematics: The problems presented by curricular choice.* Paper presented at the annual conference of the American Educational Research Association, New York.

Ryan, P. (1994). Teacher perspectives of the impact and validity of the Mt. Diablo third-grade-curriculum-based alternative assessment of mathematics (CBAAM). San Francisco, CA: Far West Lab for Educational Research and Development.

Schoen, H., Cebulla, K., Finn, K., & Fi, C. (2003). Teacher variables that relate to student achievement when using a standards-based curriculum. *Journal for Research in Mathematics Education, 34*(3), 228–259.

Schoenfeld, A. (1992). Learning to think mathematically: Problem solving, metacognition, and sense making in mathematics. In D.A. Grouws (Ed.), *Handbook of research on mathematics teaching and learning* (pp. 334–370). New York: Macmillan.

Shepard, L. (1994). Second report on case study of the effects of alternative assessment in instruction. *Student learning and accountability practices: Project 3.1. Studies in improving classroom and local assessments.* Washington, DC: Office of Educational Research and Improvement.

Shepard, L. (2000). The role of assessment in a learning culture. *Educational Researcher, 27*(7), 4–14.

Webb, N.L., & Coxford, A.F. (Eds.). (1993). *Assessment in the mathematics classroom.* Reston, VA: NCTM.

Wiggins, G. (1994, October). Toward better report cards. *Educational Leadership 52,* 28–37.

Wood, T., & Sellers, P. (1997). Deepening the analysis: Longitudinal assessment of problem-centered mathematics program. *Journal for Research in Mathematics Education, 28*(2), 163–186.

*Contemporary Issues in Early Childhood*, Volume 3, Number 2, 2002

# Computers in Early Childhood Mathematics [1]

**DOUGLAS H. CLEMENTS**
*University at Buffalo, State University of New York, USA*

ABSTRACT Computers are increasingly a part of the lives of young children. This article reviews empirical studies that have investigated the implementation and use of computers in early childhood mathematics, from birth to grade 3. Major topics include general issues of children using computers, the use and efficacy of various types of computer programs for teaching and learning mathematics, and effective teaching strategies using computers.

## Children Using Computers

Most schools have some computer technology, with the ratio of computers to students changing from 1:125 in 1984 and 1:22 in 1990 to 1:10 in 1997 (Clements & Nastasi, 1993; Coley et al, 1997). However, schools having computers does not mean children use computers. In one study, just 9% of fourth graders (they did not collect data on younger children) said they used a computer for schoolwork almost every day; 60% said they never used one. A study of preschool and kindergarten classrooms indicated low use by most teachers (Cuban, 2001). Nevertheless, there seems to be an increasing *potential* for children to use computers in early childhood settings. Is such use appropriate?

An old concern is that children must reach the stage of concrete operations before they are ready to work with computers. Research, however, has found that preschoolers are more competent than has been thought and can, under certain conditions, exhibit thinking traditionally considered 'concrete' (Gelman & Baillargeon, 1983). Furthermore, research shows that even young pre-operational children can use *appropriate* computer programs (Clements & Nastasi, 1992). A related concern is that computer use demands symbolic competence; that is, *computers* are not concrete. This ignores, however, that much of the activity in which young children engage *is* symbolic. They communicate with gestures and language, and they employ symbols in their play, song, and art (Sheingold, 1986).

Moreover, what is 'concrete' to the child may have more to do with what is meaningful and manipulable than with physical characteristics. One study compared a computer graphic felt board environment, in which children could freely construct 'bean stick pictures' by selecting and arranging beans, sticks, and number symbols, to a real bean stick environment (Char, 1989). The computer environment actually offered equal, and sometimes greater, control and flexibility to young children. Both environments were worthwhile, but one did not need to precede the other. Other studies show that computers enrich experience with regular manipulatives. Third-grade students who used both manipulatives and computer programs, or software, demonstrated a greater sophistication in classification and logical thinking, and showed more foresight and deliberation in classification, than did students who used only manipulatives (Olson, 1988).

Others argue that brain research indicates that children should not use computers (Healy, 1998). One could disagree with the interpretations of the research and its ramifications, but for our purposes, let it suffice to say that few neuroscientists believe that direct educational implications can be drawn from their field (Bruer, 1997; Cuban, 2001) – the implications are unwarranted and probably spurious. Finally, recent reports bring up the old issue of 'rushing' children. However, computers are no more dangerous than many of the other materials we use with young children, from pencils to books to tools; one can push a child to read or engage in other activities inappropriately early. They can all also be used to provide developmentally appropriate experiences. Furthermore, the construct of 'developmental appropriateness' continues to be refined. Following the National Association for the Education of Young Children (NAEYC), we define it as follows: developmentally appropriate means challenging but attainable for most children of a given age range, flexible enough to respond to inevitable individual variation, and, most important, consistent with children's ways of thinking and learning (Clements et al, in press). Therefore, the question is not if computers are 'concrete,' but whether they provide experiences that facilitate children's learning. Criticism (or proselytizing) not grounded in practice is unreliable. As just one initial example, critics have said, about children drawing shapes by giving Logo programming commands to a screen 'turtle', 'What does it mean to children to command a perfect square but still not be able to draw it by themselves?' (Cuffaro, 1984, p. 561). Research indicates, however, that Logo drawing experience allows some children to create pictures more elaborate than those that they can create by hand. Children modify their ideas and use these new ideas in all their artwork (Vaidya & McKeeby, 1984). Thus, what it means is that children can extend their experiences and their creative activities in learning to draw. Therefore, there seems to be no reason not to use computers *if* they can contribute to mathematical learning. Substantial evidence has also been generated addressing this question.

## Computers, Mathematics, and Reasoning

Research has substantiated that computers can help young children learn mathematics. For example, one computer-based project showed positive and statistically significant improvement across grades and schools for three areas, reading, mathematics, and total battery scores (Kromhout & Butzin, 1993). Effects were largest for students in the program for more than one year, as well as those from minorities and free-lunch programs. In this section, I review research on computer-mediated practice, on-computer manipulatives, turtle geometry, and computer approaches to developing higher-order thinking skills.[2] For each of these, I describe some unique advantages of computers for educational practice.

### *Computer-mediated Practice*

Children can use computer-assisted instruction (CAI) to practice arithmetic processes and to foster deeper conceptual thinking. Drill and practice software can help young children develop competence in such skills as counting and sorting (Clements & Nastasi, 1993). Indeed, the largest gains in the use of CAI have been in mathematics for *primary* grade children, especially in compensatory education (Ragosta et al, 1981; Lavin & Sanders, 1983; Niemiec & Walberg, 1984). Again, 10 minutes per day proved sufficient for significant gains; 20 minutes was even better. This CAI approach may be as or more cost-effective as other instructional interventions, such as peer tutoring and reducing class size (Niemiec & Walberg, 1987). Properly chosen, computer games may also be effective. Second graders with an average of one hour of interaction with a computer game over a two-week period responded correctly to twice as many items on an addition facts speed test as did students in a control group (Kraus, 1981).

How young can children be and still obtain such benefits? Three year-olds learned sorting from a computer task as easily as from a concrete doll task (Brinkley & Watson, 1987-88a). Reports of gains in such skills as counting have also been reported for kindergartners (Hungate, 1982). Similarly, kindergartners in a computer group scored higher on numeral recognition tasks than those taught by a teacher (McCollister et al, 1986). There was some indication, however, that instruction by a teacher was more effective for children just beginning to recognize numerals, but the opposite was true for more able children. Children might best work with such programs once they have understood the concepts; then, practice may be of real benefit. In addition, students with learning difficulties might be distracted by drill in a game format, which impairs their learning (Christensen & Gerber, 1990).

Unique capabilities of computers for providing practice include: the combination of visual displays, animated graphics and speech; the ability to provide feedback and keep a variety of records; the opportunity to explore a situation; and individualization. However, exclusive use of such drill software